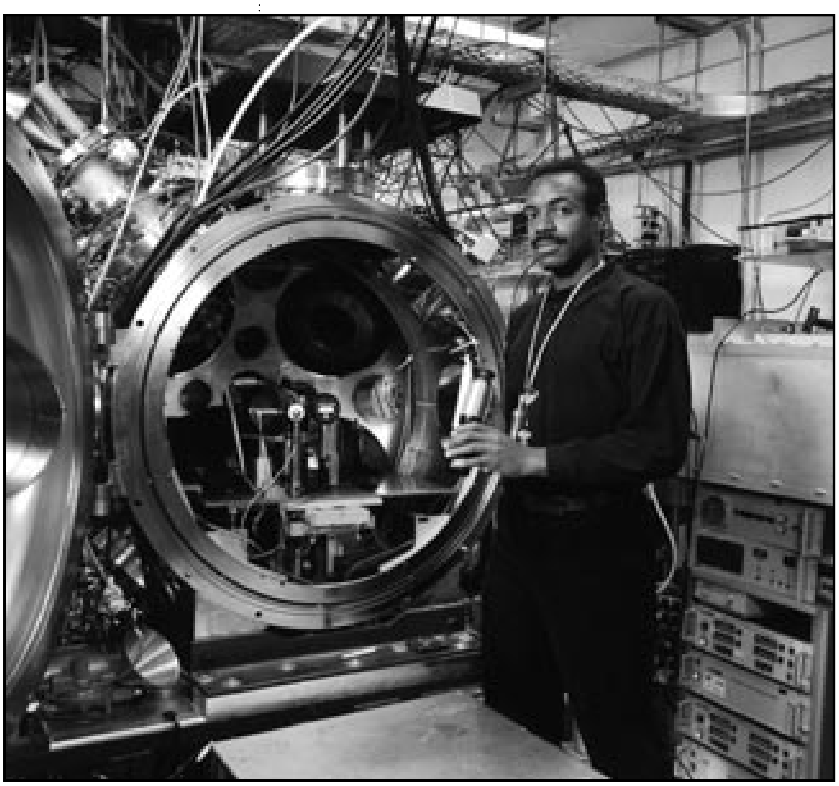
Experimental Science

Recognizing the changes mandated by the two-year-old U.S. moratorium on underground nuclear testing, LLNL is using its testing expertise to support other program areas. With 40-plus years in the "testing business," our goal in the last year has been to enter areas that can benefit from our unique experience.

With changing national priorities, the demands for LLNL's nuclear testing expertise changed, too. However, we expect the national demand for challenging and complex technologies to continue, and we believe we must be ready to respond to meet other needs in global security. Thus, our focus is threefold: retain our core competencies in nuclear testing through experimental and calculational studies, redirect our specialized technologies to new nationwide priorities, and restructure our organization to respond to new sponsors and customers. Our structural changes are indeed under way: the Nuclear Test and Experimental Science directorate was dissolved mid-year. Projects once solely within the directorate are now broadly integrated with other Laboratory programs, into areas such as nonproliferation, weapon physics, and earth sciences.

The sub-picosecond x-ray streak camera for the ultrashort-pulse laser target chamber is shown with its developer, Ronnie Shepard. The camera will be combined with a high-resolution x-ray spectrometer to measure time-resolved emission spectra from buried layers in short-pulse targets for determining plasma opacity.



Of particular importance now is our participation in experimental science for LLNL's science-based stockpile stewardship program. This year we emphasized secondary-weapon physics applications to stockpile stewardship and the initiation of participation by the Department of Energy/Nevada field contractor in primary weapon-physics experiments. Our secondary-weapon-physics experiments were centered on technologies for producing and diagnosing plasmas with applicable temperatures and densities. We used these laser-produced plasmas to drive radiation transport, opacity, and interface instability experiments.

Weapon-Physics Experiments

Ultrashort-Pulse Laser

Our ultrashort-pulse laser project heats target materials to kilovolt temperatures so rapidly they have no chance to expand, thus creating a short-lived, solid-density, high-temperature plasma appropriate for research into weapon-condition physics. The ultrashort-pulse laser gives us a unique capability to produce and study hot dense matter at well-defined density and temperature conditions similar to stellar interiors, inertial fusion plasmas, and nuclear explosions. We can currently focus up to 6.6×10^{18} W/cm^2 of 800-nm light on target for about 100 fs. Most importantly, we have developed techniques to assure that the low-power precursors in the light pulse, which once preheated and expanded target material prematurely here and elsewhere, have been eliminated.

To control the precursors, we built and tested a pulse stretcher with optical components that allow us to control the phase distortion of pulse experiences during stretching, compression, and amplification. We have been able, with near perfection, to recompress 100-fs-pulse input to the amplifier to a duration of 105 fs. Our recompressed pulse displays a higher fidelity than any in previous work. We believe continuous phase control represents the next step in the evolution of chirped-pulse amplification and will permit the generation of cleaner and even shorter pulses for high-intensity laser–matter interactions.

We have used our high-contrast ultrashort-pulse laser at 400 nm at intensities to 10^{18} W/cm^2, where the laser has excellent contrast and no precursors, to measure the energy absorption of 100-fs pulses by a variety of transparent, metallic, and high-atomic-number materials. The data from this first quantitative study of material-dependent absorption with clean ultrashort pulses at high intensities may show new absorption mechanisms and are consistent with the production of solid-density surface plasmas with the ultrashort-pulse laser.

The transport of energy from the hot surface into bulk target material is predicted to take place supersonically, leading to larger volumes of heated high-density plasma in the bulk. To measure this effect, we built a new magnetically separated, ion time-of-flight spectrometer to observe the velocity distribution of ions from tracer layers buried at varying depths below the target surface. We will use the data, which indicate that ultrashort laser pulses produce temperatures in excess of several hundred volts, to refine our model of energy transport in the plasma.

We are designing equation-of-state (EOS) and opacity experiments using the unique features of the ultrashort-pulse laser. We are also constructing an optical probe with a time resolution down to 20 fs to measure the plasma expansion after the pulse and, thus, the EOS effect in the expansion. Opacity measurements will be made using time-resolved emission spectra from buried layers in short-pulse targets. For these emission studies, we will combine our subpicosecond x-ray streak camera with a high-resolution x-ray spectrometer. As a direct measurement of plasma opacity, we will use a short burst of x rays from a secondary target to backlight the sample and then, by spectrally resolving the attenuated backlighter, measure the plasma opacity of low-temperature samples.

BEEF

To better understand nuclear weapon primary stages, we applied our nuclear test skills to establish a Big Explosives Experiment Facility (known as BEEF) at the Nevada Test Site (NTS). BEEF will allow the Laboratory to conduct large hydrodynamic experiments using charges far larger than those allowed at Site 300. Charge size at the NTS is essentially unrestricted, the infrastructure developed for nuclear testing is in place, and buried, reinforced concrete structures from atmospheric testing days are modifiable and usable.

Working with B-Program, we developed a facility design with a five-station, high-speed optics recording facility and control room and a laser illumination system. X-ray radiography will be possible by using Febetron electron accelerators housed in hardened chambers on the firing table. In early 1995, we will conduct certification tests using up to 2300 kg of

Highlights for 1994

- Dissolved the 40-year-old test program.
- Improved ultrashort-pulse-laser quality by controlling low-power precursors in energy delivery to the target.
- Built a spectrometer to determine temperatures within ultrashort-pulse-laser targets by analyzing ion velocities from buried tracer layers.
- Established a hydrodynamic test facility at the Nevada Test Site.
- Built a high-sensitivity mobile gas-analysis system that will be field-tested in 1995.
- Designed a radiation detector 10 to 100 times more sensitive than current detectors.
- Determined unique isotopic “fingerprints” for specific stockpile weapons.
- Developed a portable high-resolution gamma detector with a miniature mechanical cooling system.
- Improved ion-probe resolution and sensitivity for analyzing isotopic content of even microscopic environmental samples.
- Used test techniques to track groundwater movement by age and source.
- Interconnected computers in clusters using high-bandwidth electro-optic expertise.
- Brought fabrication costs for electro-optic systems in line with requirements for mass production.
- Studied new materials for opto-electronic and photonic applications.

A major construction project at the Nevada Test Site, BEEF (Big Explosives Experiment Facility) is using underground bunkers from atmospheric tests (seen unearthed here) as a base facility for large-mass hydrodynamic diagnostics experiments.

explosives to certify diagnostics bunkers for manned operation.

Test Readiness

Exercises

We maintained test readiness by conducting realistic exercises focused on arming and firing, timing and control, and diagnostic data-recording systems, as well as on downhole emplacement, device delivery, and installation at ground zero. In collaboration with Los Alamos National Laboratory and the U.K.'s Aldermaston Laboratory, we also conducted two postshot drilling and sample-recovery operations to test all aspects of a normal drillback. These exercises allowed us to review, evaluate, and document operations not normally performed during a test moratorium, and they served as opportunities for training.

Hydronuclear Experiments

We explored cost-effective ways to maximize the data return from low-yield (less than 1.8 kgs TNT-equivalent nuclear yield) experiments should they be authorized. We also used analytical and computer simulations to describe an emplacement and containment scheme that reduced burial depth to that accessible by inexpensive auger drilling. This plan was reviewed by the DOE Containment Evaluation Panel as part of a training exercise.

Anticipating that compliance with future treaties may require us to measure the nuclear yield of such experiments, we determined that fission-product gas diagnostics is the most cost-effective and accurate measurement method and joined with EG&G to build a mobile gas analysis system. This system, which will be field-tested in 1995, replaces and improves on equipment used for gas sampling in nuclear explosion diagnostics. It is centered around a quadrupole gas mass-spectrometer and a gas-handling manifold suitable for either gas or water samples.

Dual-Benefit Technologies

DOE has authorized the use of defense-program resources for activities sponsored by others, provided those activities are synergistic with defense-program goals for maintaining test readiness. LLNL and contract personnel have both worked in a number of such projects.

Groundwater Characterization at NTS

The DOE's long-term groundwater characterization project to assess the role of groundwater in transporting radioactivity away from testing centers brought our logging experts together with IT Corporation to define the saturated and vadose zones at the NTS. Conventional petroleum practices do not always work well at the NTS, so we developed custom data-processing procedures for these logs. We also used our expertise in seismic reflection techniques to develop a data-acquisition program to help the project eliminate several holes from its drilling program.

Near-field studies recommended by our radiochemists and hydrologists will define our research program over the next several years. These studies will incorporate refinements of our radionuclide source-term inventory of debris from all 825 underground tests from 1957 to 1992, kinetic studies of the solubility of nuclear explosive melt glass and debris, and equilibrium geochemical modeling of cavity waters. We will also review test phenomenology and assess the nonradiological contaminant inventory that underground testing introduced to groundwater.

Radiation Detector Development

The detector technologies once required by the test program are now finding use in materials management, international safeguards, proliferation response, waste characterization, and environmental monitoring. Work to develop advanced detector systems, signal-processing techniques, and spectral analysis methods is in progress.

We completed the initial design of a gamma-ray detection system composed of an array of high-purity germanium crystals that will provide detection sensitivities 10 to 100 times higher than currently available. The signals from the detectors are processed with an event-mode data-acquisition system to obtain sensitive signatures of isotope decay on samples of interest, such as in the radiochemical analysis of nuclear materials or explosion debris. We also performed Monte Carlo calculations of several array geometries and did preliminary tests with a two-detector system.

In the past year, we began a proof-of-principle experiment to use high-frequency information from gamma-ray signals recorded on high-purity germanium detectors. This information, which is lost in the conventional signal-shaping process, is useful for improved background suppression and for determining where in the detector a gamma ray has interacted.

Nonproliferation and Counterproliferation

Attribution and SNM Origins

We continued work with LANL and the Air Force Technical Applications Center on the attribution of special nuclear materials (SNM) and nuclear explosion debris. Using analytic techniques now being developed, we will be able to provide country-of-origin data in time of crisis, allowing national leaders to respond appropriately and with confidence.

We demonstrated unique isotopic “finger-prints” specific to U.S. stockpile weapons and, by inference, to other devices and components. For example, we analyzed a sample of uranium radiochemically and derived methods to determine the date of last chemical separation, the reactor irradiation of feed materials, the chemical steps used in purification or casting, and the signatures of other heavy elements in the production plant.

Safeguards

We have been working on remote-location detector systems as part of a program to safeguard plutonium and highly enriched uranium. To avoid weight limitations and meet field-support requirements, we developed a germanium gamma-ray detector that has a miniature cooling unit to maintain the detector’s 80-K operating temperature. The next step is a portable, robust package that is fully competitive with liquid-nitrogen-cooled detectors.

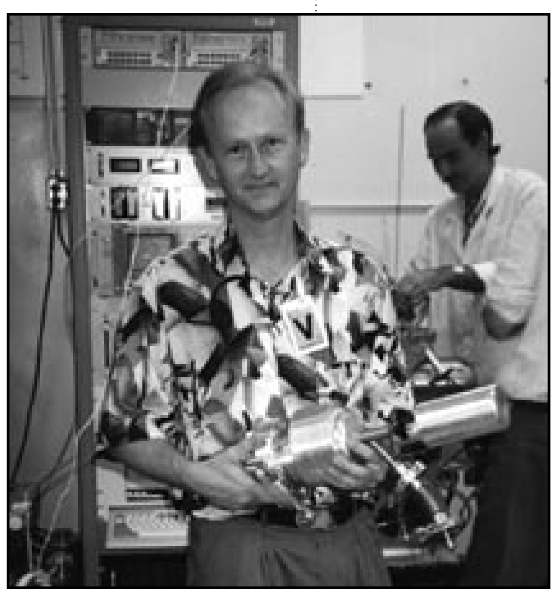
We have already developed a cadmium–zinc–tellurium solid-state detector that can do an accurate isotopic assay of uranium samples when operating at room temperature. Tests with two sizes of detectors and uranium samples of varying enrichment showed good results (10% accuracy) with a detector energy resolution of less than 3.5 keV.

Ion Probe

To improve our measurement of elemental abundances and isotopic ratios in even microscopic samples collected in and around suspected nuclear-proliferation sites, we have been developing several hardware improvements for the ion microscope, including upgrading its secondary-ion system. This upgrade will lower detection thresholds, provide higher mass-resolving power, and significantly improve imaging capability at a tenth of the cost of a new microscope.

Remote Sensing

We have been using our LIFTIRS (Livermore Fourier-transform infrared spectrometer) imaging spectrometer to form images of invisible atmospheric trace gases. It works by taking 128-by-128-pixel spatial



Ken Neufeld holds an innovative mechanical cryogenic refrigerator, developed in collaboration with an industrial partner, to integrate with a germanium detector to be the heart of a portable very-high-resolution gamma spectrometer for safeguards applications in the field.

This hot-water drilling experiment's results—tracing radionuclide migration in NTS groundwater—are being used for broader application. Assessments are being made of other groundwater phenomena into and out of the area.

images through an interferometer. Between frames, a mirror moves, allowing each pixel to record the wavelength spectrum of incident light. By cross-correlating the spectrum recorded at each pixel with the signature spectrum of a gas or mix of gases, we can display an image of the corresponding gas. This allows us to monitor plumes from stacks or leaks from reservoirs, check industrial operations for evidence of illegal activities, and study atmospheric phenomena.

We also developed a mobile laboratory so LIDAR (the laser analog of radar) can probe aerosols in the atmosphere. We have demonstrated our ability to locate vehicle exhaust plumes even when they are subvisible and to locate sources by mapping the distribution of plumes in space. To evaluate sensors for pollution and proliferation monitoring, we helped establish a remote-sensor test range at the NTS. This range can release test plumes of more than 12 toxic gases at concentrations up to 1000 ppm and can test instruments, on the ground or in airborne platforms, up to 10 km away.

Isotope Measurements for Groundwater

We have been using techniques for measuring isotope tracers in diagnostics to study the movement of groundwater, which supplies about half of California's water needs. Noble gases, hydrogen, and oxygen isotopes tell us the temperature, altitude, and degree of evaporation of water as it enters the saturated zone of an aquifer where, without further atmospheric interactions, trace isotope concentrations are preserved. This knowledge helps us identify recharge irrigation water and distinguish between water entering the aquifer at different elevations and temperatures.

We can also determine the age of water by the amount of radioactive tritium and ^{14}C it contains. For example, tritium and its stable daughter ^{3}He can accurately date water that is less than 50 years old, while new techniques using accelerator mass spectrometry to measure ^{14}C can date groundwater between about 1,000 to 40,000 years of age.

We provided the Kansas Geological Survey with water age and origin measurements to calibrate a hydrogeological model of groundwater movement in the Dakota aquifer. In Yosemite National Park, we determined recharge locations and groundwater ages to help the U.S. Geological Survey (USGS) quantify the size of rechargeable (and therefore usable) groundwater resources in the Wawona Valley. We also helped the USGS assess the characteristics of water flow in fractures by injecting five noble gas tracers into an artesian well in fractured granite, subsequently measuring their concentration. In addition, we helped California's Orange County Water District determine the age of injected reclaimed water to ensure that it had been underground long enough to satisfy potability requirements.

Communications, Computing, and Data Interconnects

Last year, we described innovative high-bandwidth electro-optic components that are advancing state-of-the-art communications. Similar technologies are now being applied to communications between computer processors and memory. Because the bandwidth requirements for such communications often exceed those attainable with metallic interconnects, particularly at high processor clock speeds and long interconnect distances, we are working with the Optoelectronics Technology Consortium on an optically interconnected workstation cluster whose interconnect distances could be tens of meters.

One impediment to the widespread use of optical interconnects within a computer is the cost of the high-performance components. A key driver of this cost is the precision required to attach fiber-optic "pigtails" to the guided-wave optical device, a job currently done by highly trained technicians who must look through a microscope to manipulate the elements. With LLNL's binocular machine-vision technology and a coarse–fine automated positioning strategy, we will use robotics for a hundredfold reduction in cost. This work is being done in collaboration with United Technologies Photonics, ORTEL, Newport–Klinger, and the MIT Manufacturing Institute.

We will assure further automation by positioning the fiber-optic pigtail on a silicon microbench formed by precision etching. Once positioned, the solder-tinned pigtail can be affixed to the silicon substrate by using polysilicon heaters in the substrate to reflow the solder.

Opto-Electronics and Photonic Materials

We have been studying silicon nanocrystals (porous silicon) and electroluminescent polymers for opto-electronics and photonic applications such as color flat-panel and three-dimensional displays, light-emitting diodes (LED), and lasers. In collaboration with UC Davis, we made silicon nanocrystals that photoluminesce throughout the visible. We also made arrays of miniature, porous, silicon-based LEDs that emit throughout the visible and infrared, as well as inexpensive, mechanically flexible LEDs of electroluminescent polymers.

We have also been studying fullerenes—soccer-ball-shaped carbon molecules consisting mainly of 60 or 70 carbon atoms—for applications like optical switching, nonlinear waveguides, and optical limiting. Fullerene switches are competitive with optical-fiber switches but are smaller, easier to fabricate, and potentially faster. Recently we used a thin film of ^{70}C and a new device design to demonstrate the first fullerene-based, all-optical switch.

Nuclear Physics

We continued to explore enhanced nuclear stability near the predicted deformed shells at Z=108 and N=162 with scientists at the Joint Institute for Nuclear Research in Dubna, Russia. To analyze reaction products, we used an on-line, gas-filled electromagnetic separator and a position-sensitive surface-barrier detection system preceded by the Dubna U400 cyclotron and a rotating wheel target. From ^{34}S bombardments of ^{238}U, we discovered a new nuclide of element 108, with mass 267, the heaviest atomic nucleus yet discovered. We will continue to study this region in hope of discovering element 110 in 1995.

We are using Berkeley's Gammasphere multidetector array and heavy-ion reactions to study extremely deformed lead nuclei at high angular momenta. These nuclei exhibit gamma-ray band structures called superdeformed bands. Recently, we identified two such bands in both ^{193}Pb and ^{195}Pb. The constant differences in energy exhibited by the gamma rays in both bands differed from all other superdeformed bands in the lead nuclei, which showed a gradual decrease in energy differences. Although current theoretical calculations attribute this decrease to a steady loss of proton and neutron pairing, further investigation will be needed to fully understand the discrepancy.

Summary

Despite the dissolution of the directorate, our people continue to find new applications for our expertise in underground nuclear testing. We expect our fully developed capabilities—as well as our ever-expanding wealth of new technologies—to help us respond to current needs in global security. Maintaining capabilities, supporting stockpile stewardship, and developing new applications for our work is evidenced by advances in such diverse fields as spectral imaging, fiber-optic telecommunications, and groundwater quality.

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